Numerical simulation of the atmospheric flow over a complex terrain at local scale using Code_Saturne: a comparison of two forest canopy models

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Objectives

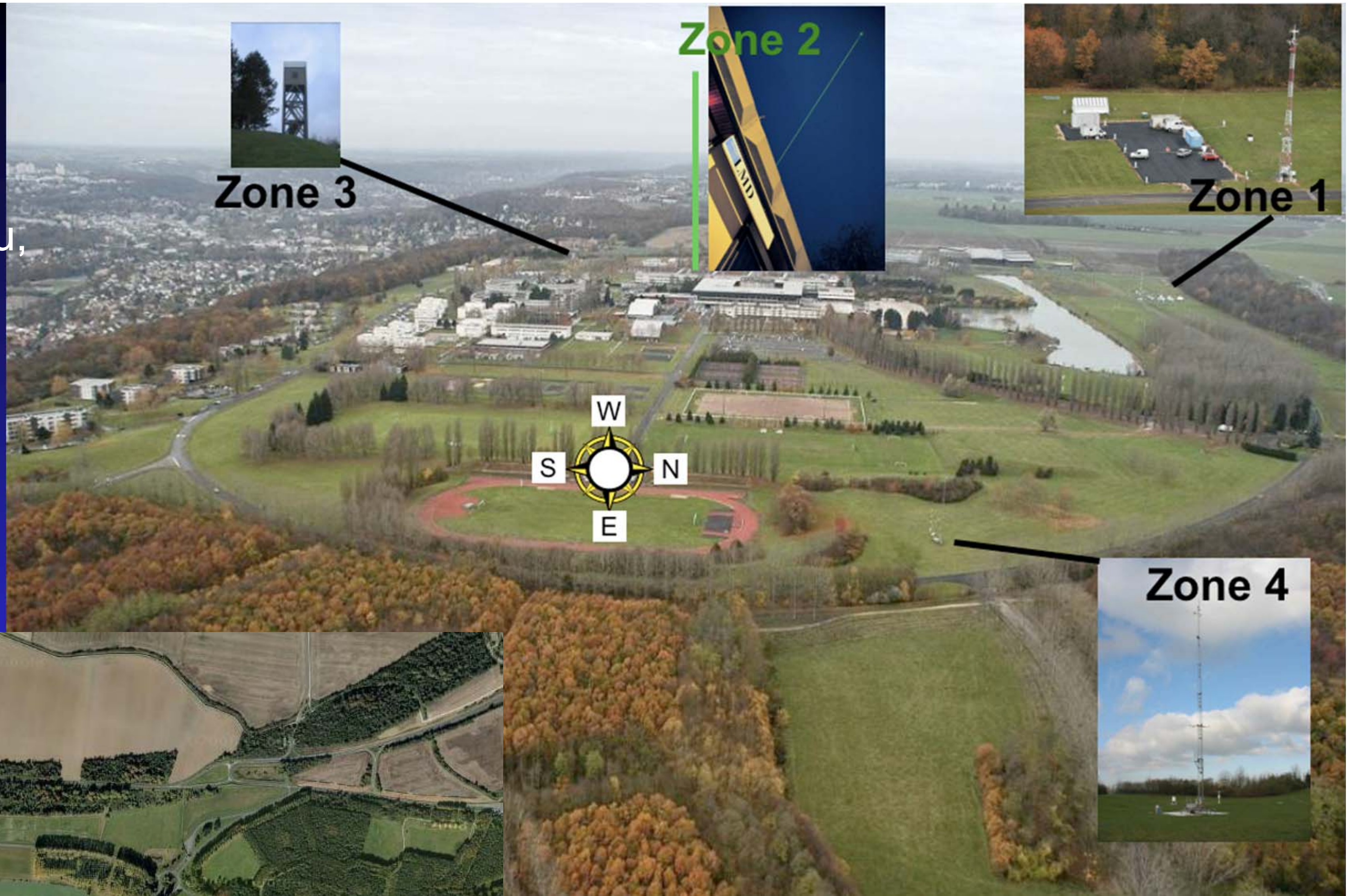
- A previous 3D study has shown a strong impact of the forested area in a semi industrial inhomogeneous site.
- To find the best canopy model adapted to simulate the aerodynamic effects of forested areas on turbulent kinetic energy at the SIRTA site, using 3D simulations and by comparison with measurements collected during 36 months (January 2007-December 2009).

Outline of presentation

- Site description
- Numerical model
- Comparaison between numerical and experimental results
- Conclusion and further works

S.I.R.T.A.

Located in Palaiseau, 20 km south of Paris (France) in a semi urban environment.



SIRTA Satellite view showing the buildings, forest, lake and two instrumented zones(zone1, zone4)

CFD code

• Numerical simulations performed using *Code_Saturne* (atmospheric module) based on the finite volume co-localized method.

(open source : www.code-saturne.org, code-saturne.info)

• Turbulence is modeled using the standard k-ε turbulence closure.

• The CFD code Code_Saturne can take into account the thermal stratification (stable and unstable) but only neutral presented here

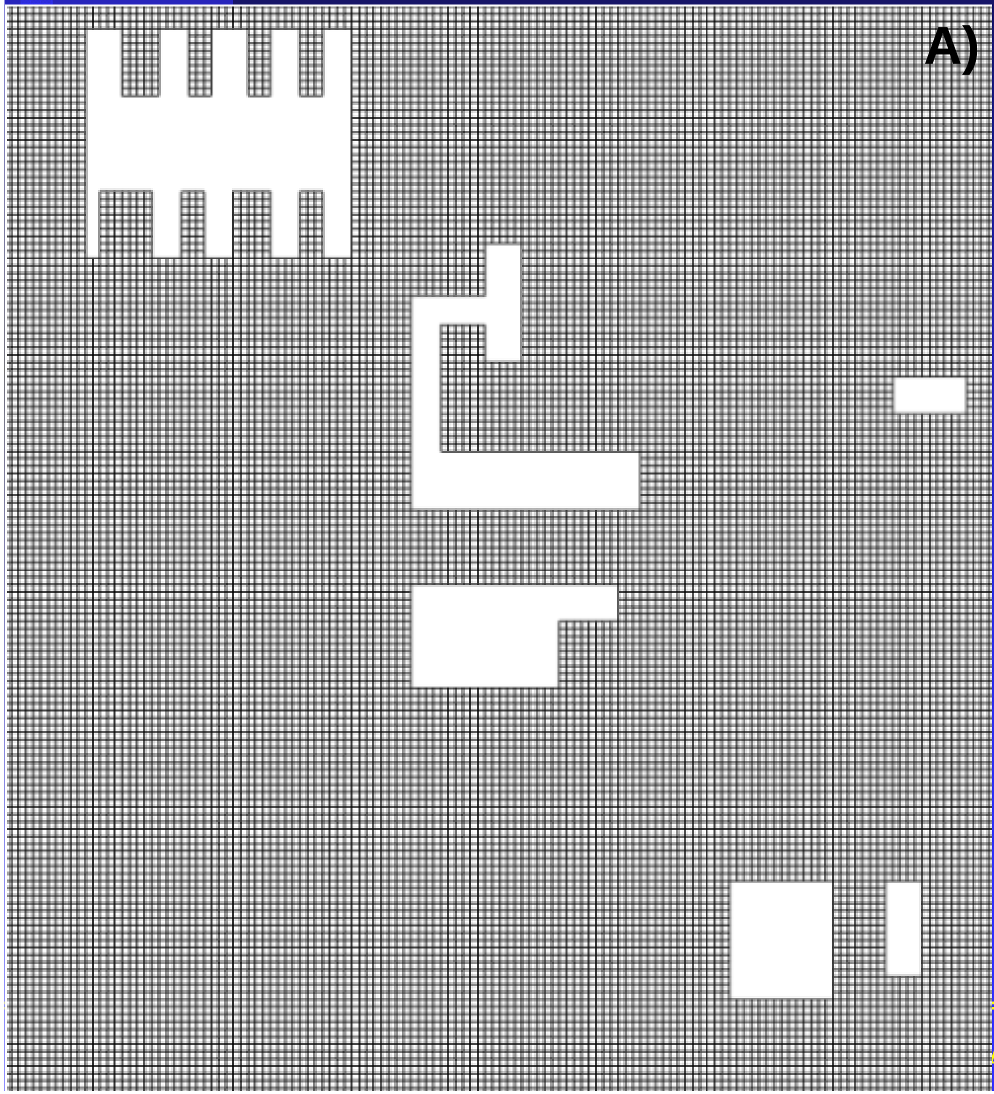
• In this study, we are interested in the dynamical flow only, hence microphysics of water and radiative processes are not activated.

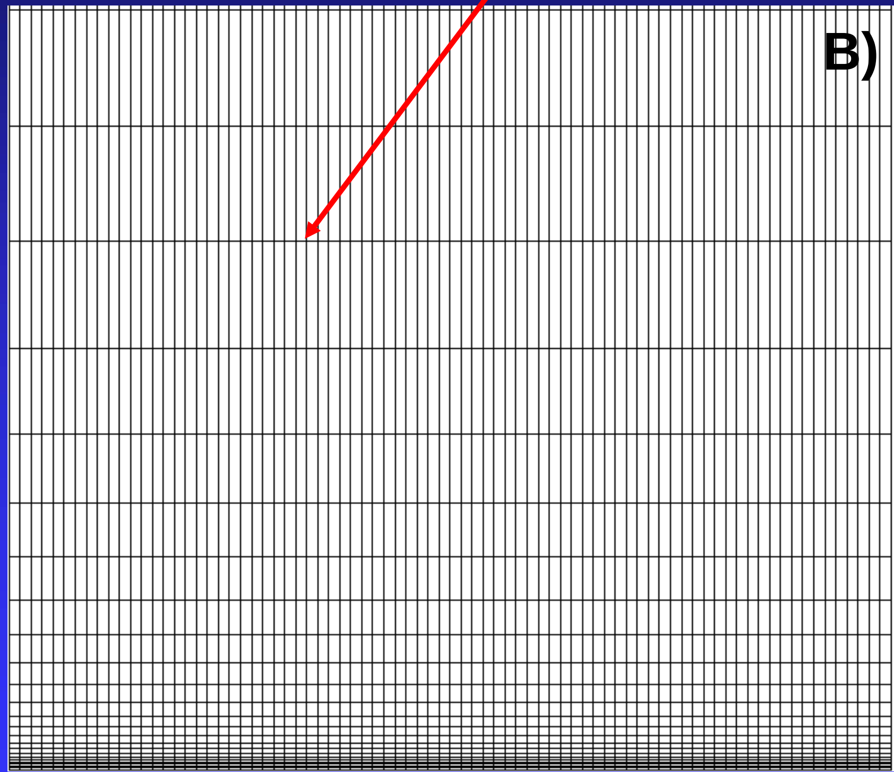
Mesh of the fluid domain

- Gambit { $6\ 10^6$ cells, 90 vertical levels }

Progressive mesh (decrease the computational time)

Quadrangle shapes





Mesh of the fluid domain, A) horizontal cross section at ground level, B) in a vertical plane

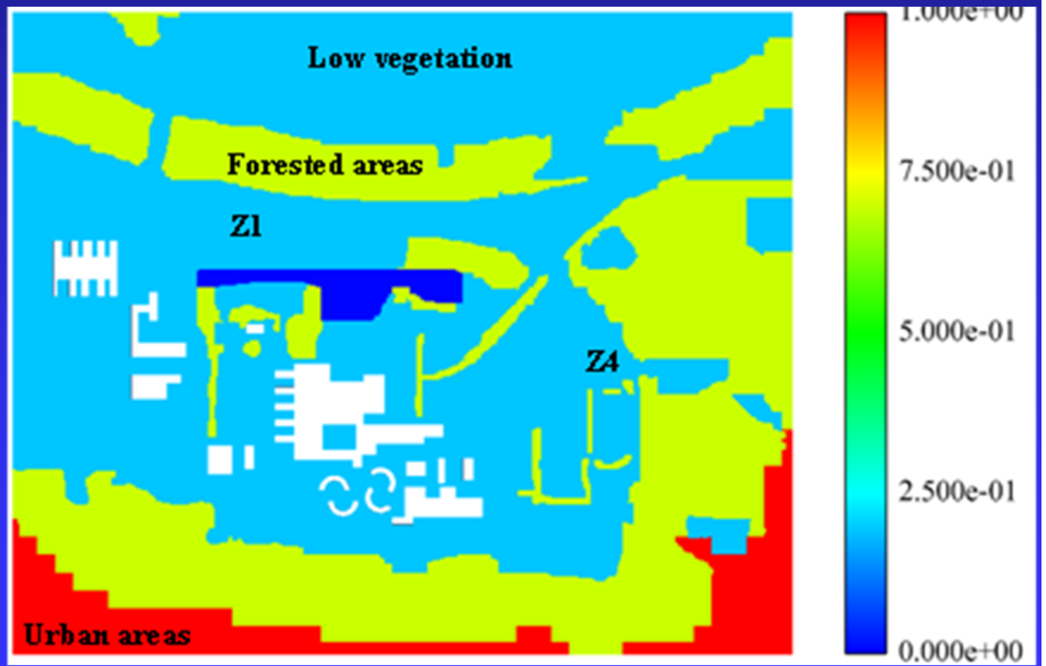
Land Use Cover

Land Use Cover (LUC) from French Institute of Geography (resolution : 50m)

Modification of this initial map according to satellite view (resolution: 5 m)

→ ground roughness

SIRTA site



Land use map

✓ Drag porosity model

The drag models which have been implemented in *Code_Saturne* are based on the models of Svensson (2000) and Katul (2004).

- F_i is added as a source term in the Navier-Stokes equation:

$$F_i = -\frac{1}{2}\rho\,\alpha\,C_D\,|U|\,\overline{U}_i$$

α : Leaf area index (0,5), H : Tree height H (15m), C_D : Drag coefficient (0,2)

- additional source terms S_k, S_ε in k and ε equations :

Svensson (2000)

$$S_k = \frac{1}{2}\rho\,\alpha\,C_D\,|U|^3$$

$$S_\varepsilon = \frac{\varepsilon}{2k}C_{4\varepsilon}\rho\,\alpha\,C_D\,|U|^3$$

$C_{4\varepsilon} = 1.95$

Katul et al. (2004)

$$S_k = \frac{1}{2}\rho\,\alpha\,C_D\,B_p\,|U|^3 - \frac{1}{2}\rho\,\alpha\,C_D\,B_d\,k|U|$$

$$S_\varepsilon = \frac{\varepsilon}{2k}C_{4\varepsilon}\rho\,\alpha\,C_D\,|U|^3 - C_{\varepsilon 5}B_d\,\varepsilon\,|U|$$

$B_p=1$
$B_d=0.5$

$C_{4\varepsilon} = C_{\varepsilon 5} = 0.9$

✓ Comparison measurements/simulations

• Mean Wind and turbulence have been measured with a sonic anemometer at 10 m in zone 1 and at 10 m and 30 m in zone 4, for 36 months (January 2007-December 2009).

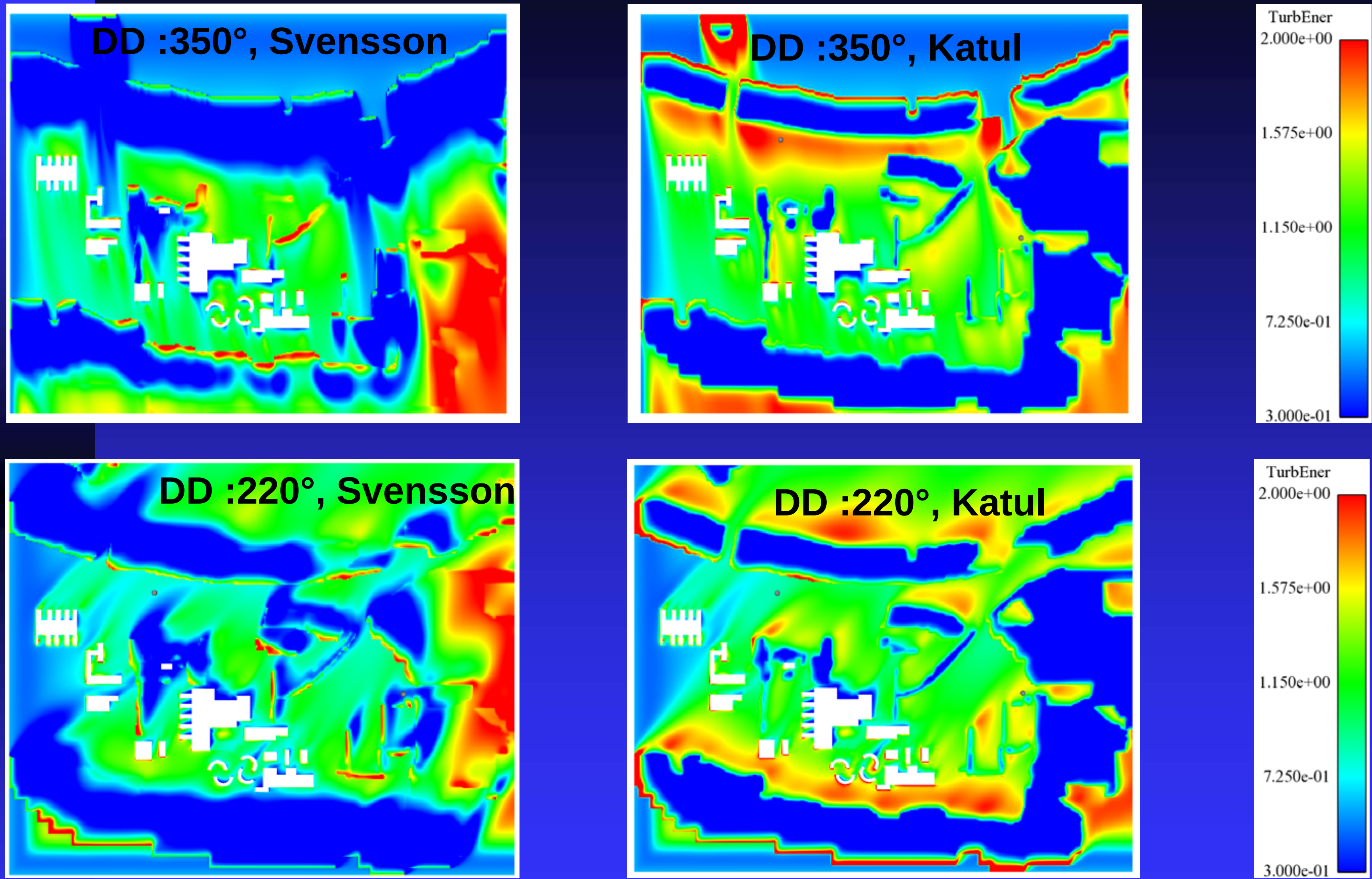
• These data have been classified according to the stability of the atmosphere by using the difference ΔT between the heights of 10 and 30m at zone 4 and Monin-Obukhov lenght.

• The cases close to neutral stability are selected (-0,1°C< ΔT < -0,3°C and |Lmo| > 500 m)

• They are classified according to direction sectors of 10°.

• The normalized TKE has been calculated for all directions and compared to the numerical results.

Horizontal cross sections of horizontal TKE



Horizontal cross sections at Z=10m of horizontal TKE obtained using Svensson and Katul models for wind directions 350° and 220°.

✓ Comparison measurements/simulations - Zone 1

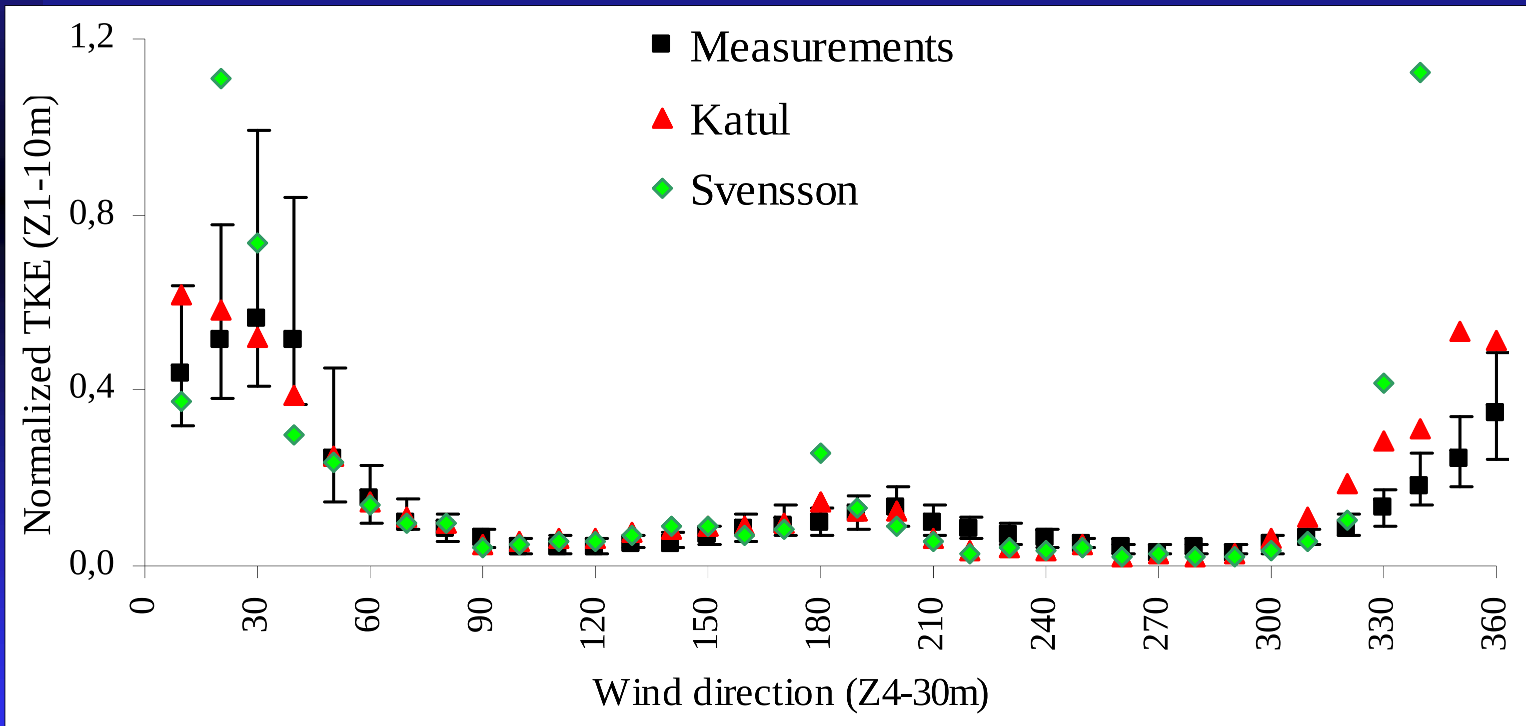
• Measurements : the production of turbulence is dominated by the effect of the northern canopy for 330° <DD<70°.

• Katul canopy model : The normalized TKE agrees well with measurments for10<DD<330°.

slightly overestimated for 320°<DD<350°

• Svensson canopy model : The normalized TKE is strongly overestimated for 330°<DD<360°

Good agreement with measurements for 50°<DD<320°



Comparison with measurement of the calculated normalized TKE obtained using Svensson and Katul canopy models for zone 1 as a function of wind direction. The vertical bars indicate the percentile 10 and 90 of the measured values (10 mn aveARAGED).

✓ Comparison measurements/simulations – Zone 4

- Measurements : The variation of measured normalized TKE is more uniform

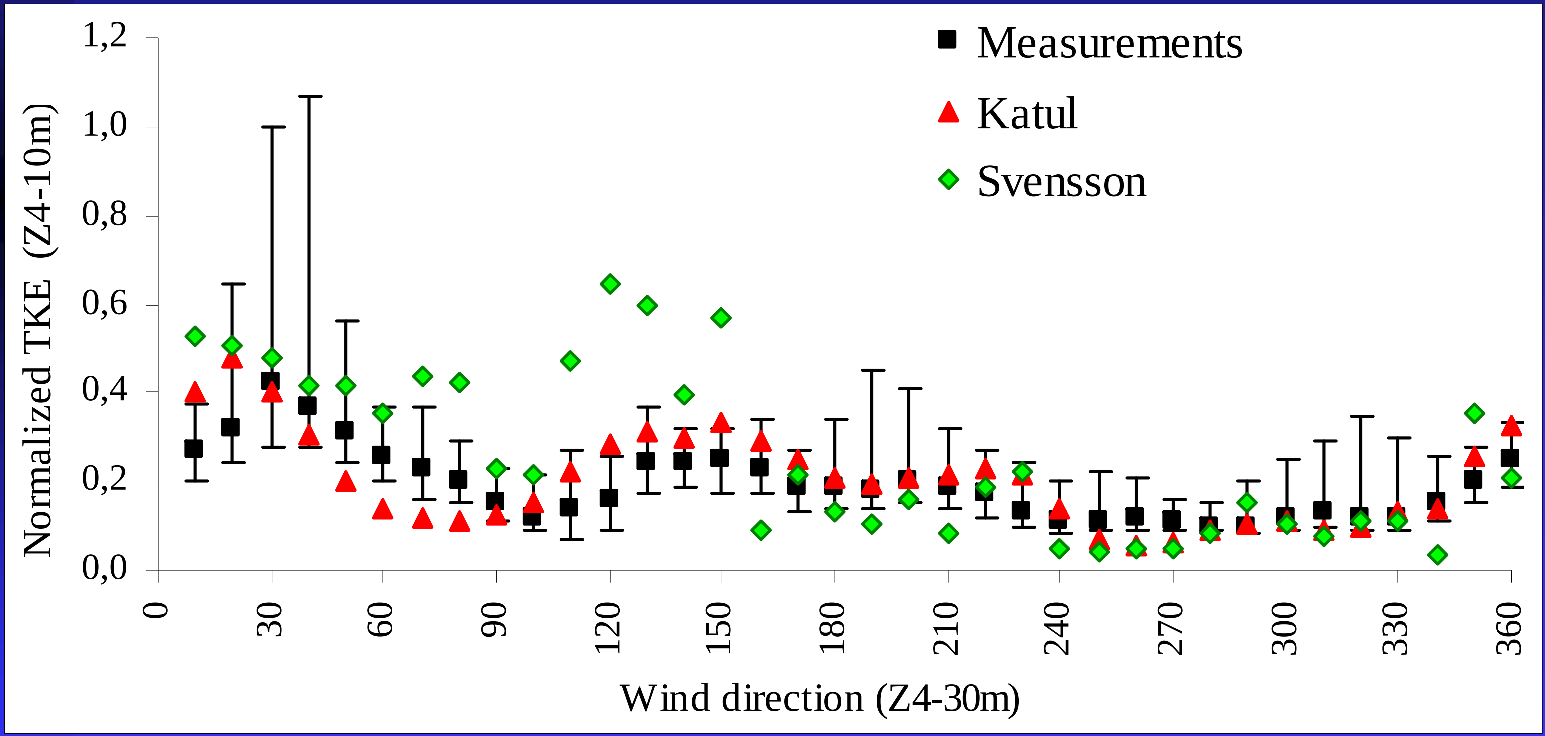
  The high values are obtained downwind the eastern canopy

- Katul canopy model : The normalized TKE agrees well with measurements for 10<DD<40° and 90<DD<360°

  Slightly underestimated for 50°<DD<80°

- Svensson canopy model : Good agreement with measurements for 20°<DD<60° and 280°<DD<330°

  Strongly overestimated for 110°<DD<150°



Comparison with measurment of the calculated normalized TKE obtained using Svensson and Katul canopy models at 10 m for zone 4 as a function of wind direction.

Conclusions

The atmospheric module of Code_Saturne was used in 3D to investigate two canopy models (Svensson and Katul's) to find the most suited to simulate the airflow over the experimental SIRTA site.

We found that :

- Katul's model gives the best agreement with the measurements.
- Svensson's model shows larger disagreement with the measurements in the wind sectors where the forested canopy effect is predominant
- Katul's model more physically realistic than Svensson's model.
- We confirm the results previously found in 2D.

Further works

• Comparison of numerical results with new additional measurements collected at the SIRTA site in different position and height in zone 1 and 4.

• Simulation in non neutral stability (stable / unstable) using Katul canopy model and comparison with measurements.

• Enlargement of the domain (include the surrounding valleys).

• Long term local simulation of atmospheric dispersion conditions over SIRTA site using a clustering method.

Thank you for your attention